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IRRIGATION-WATER REQUIREMENTS OF CITRUS IN THE SOUTH COASTAL BASIN OF CALIFORNIA

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IRRIGATION-WATER REQUIREMENTS OF CITRUS IN THE SOUTH COASTAL BASIN OF CALIFORNIA[1,2]

ARTHUR F. PILLSBURY,[3] O. C. COMPTON,[4] and W. E. PICKER[5]

IRRIGATION INVESTIGATIONS extending over eight years in the coastal and interior zones of Orange, Riverside, and San Bernardino counties are summarized in this, the second report on the duty of water for citrus trees in southern California. The first report, Bulletin 489,[6] described similar studies with citrus and avocados in San Diego County.

GENERAL DESCRIPTION OF THE AREA

The area covered in this investigation lies within the south coastal basin of southern California—principally within the drainage basin of the Santa Ana River and its tributaries. The so-called coastal area is the long, rather narrow strip of land lying between the coastal plains on the west and the foothills of the coastal mountains on the east, and extending from San Juan Capistrano on the south to the Santa Monica hills on the north. The principal citrus plantings are near Tustin, Santa Ana, Orange, Anaheim, Placentia, Fullerton, and La Habra of Orange County and Whittier of Los Angeles County.

The interior area consists of the basins lying between Etiwanda, Ontario, and Corona on the west and the San Gabriel and San Jacinto mountain ranges on the east. The chief citrus plantings lie in the vicinity of Rialto, San Bernardino, Highland, Redlands, Riverside, Arlington, and Corona.

The agricultural soils of these coastal and interior zones fall into three physiographic groups: (1) upland primary soils derived through the weathering and disintegration of rocks in place; (2) coastal-plains soils of the old unconsolidated valley-filling materials of water-laid character (sometimes called terrace soils); and (3) recent alluvial soils existing as flood-plain and alluvial-fan deposits.

In each of the two areas, more than half the agricultural lands lie in the flood plains and alluvial fans where the principal soils are the loams, sandy loams, and fine sands of the Hanford, Yolo, and Tujunga series and the silt

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[1] Received for publication January 2, 1943.

[2] This project was planned and largely executed by the late Professor S. H. Beckett, who in 1932 did considerable work toward summarizing the information obtained. Professor M. R. Huberty, with the assistance of O. C. Compton, afterwards secured some data on salts in the soil solution. The 1933 to 1935 data from the Corona area were furnished by Mr. Compton. Throughout the project, Mr. Picker was the principal assistant. The senior author made no significant original contribution, but, under the supervision of Professor Huberty, computed and assembled all data, and prepared the report. Credit for the study belongs mainly to Professor Beckett.

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[5] Formerly Technician in the Experiment Station; resigned December 21, 1941.

[6] Beckett, S. H., Harry F. Blaney, and Colin A. Taylor. Irrigation water requirement studies of citrus and avocado trees in San Diego County, California, 1926 and 1927. California Agr. Exp. Sta. Bul. 489:1–51. 1930. (*Out of print.*)

loams of the Chino series. In the coastal area most of the citrus plantings are on the Hanford and Yolo series.

In the interior areas in Riverside and San Bernardino counties, plantings on the alluvial soils of the Hanford and Tujunga series predominate; but large acreages are found on the Placentia and Ramona series, which comprise most of the older valley-filling material. Near Corona, plantings are mainly on Yolo soils. At the higher elevations, bordering the valleys, a few plantings have been made on the primary soils of the Vista, Fallbrook, and Altamont series.

Although the climate of both the coastal and the interior zones is featured by two contrasting seasons—a cool wet one and a warm, dry, rainless one—a wide variation is found in the rainfall and temperatures of the two sections.

The coastal zone, with a lower average elevation, has in general a somewhat longer growing season, less severe winter temperatures, and cooler summers than the interior. The temperatures during April, May, and June are usually moderated by coastal or high fogs, the maximum temperatures occurring in July and August. Occasional dry, desiccating north winds blow during the fall. In the interior, summer temperatures often extend through September; and in several localities maximum temperatures and lowest humidities for the year have been recorded during that month. Dry desert winds occur frequently during the fall and winter.

In both areas the period between April 1 and November 1 represents about the normal irrigation season, for these 7 months are almost always without benefiting rains and require high water usage. The need for winter irrigation varies widely from year to year; it depends on the frequency and intensity of the individual storms as well as on total seasonal rainfall. This fact may decidedly influence the total yearly irrigation requirement, if not the maximum rate of summer demand. In the present study, the aim was chiefly to determine the use of water during the normal irrigation season, April 1 to November 1; but scattered records have been obtained for other months.

METHOD OF PROCEDURE

The general procedure in selecting experimental plots, measuring the water applied, sampling the soil for moisture content, and making computations followed closely the methods used in San Diego County during 1926 and 1927:

> Typical orchards were selected in which the quantity of water used, the frequency of irrigation, the method of irrigation, and other factors represented standard practice of the locality. The quantity of water delivered to each farm at each irrigation was measured, and by frequent sampling of the soil for moisture content in the selected plots, a full season's record of the soil-moisture fluctuations and the rate of moisture extraction from the soil at various depths was obtained.
>
> The records of water measurements and of soil-moisture determinations were used as a basis in determining the following for each grove and for each plot: (1) the rate of use of water and the soil depths from which this water was taken; (2) the monthly and seasonal use of water by the crop under observation; (3) the percentage of water applied which could be accounted for in soil-moisture increase; (4) the monthly and seasonal irrigation requirements; and (5) the required frequency of irrigation, and depth of water to be applied at each irrigation on various soil types.[7]

[7] Beckett, S. H., Harry F. Blaney, and Colin A. Taylor. Irrigation water requirement studies of citrus and avocado trees in San Diego County, California, 1926 and 1927. California Agr. Exp. Sta. Bul. 489:7. 1930. (*Out of print.*)

Selection of Experimental Plots.—The experimental plots were located in typical citrus orchards planted on the prevailing soil types of the area, where the water supply and irrigation intervals were such that the trees would not suffer from drought during the irrigation season.

The plots in the coastal zone were on loams and sandy-loam soils of the Yolo and Hanford series. In the interior, part of the plots were on recent alluvial loams and sandy loams of the Yolo, Hanford, and Tujunga series, and part on the old valley fills represented by the Placentia and Ramona loams. Figure 1 shows the general location of the experimental fields.

Plots were located where the condition of the trees, the depth of the soil, and the soil type were representative of the entire orchard, and where the topography favored the uniform application of water. The plots selected in each orchard included one, two, or three adjacent rectangular areas cornered by four trees, all soil samples being taken from thirteen to seventeen selected points within each plot. Figure 2 shows the sampling points in relation to the trees and the irrigation furrows in a typical orchard.

Measurement of Water.—The plots in the different orchards were so situated that the water applied to them could not be measured. Whenever possible, however, weir measurements were obtained for the water delivered at each irrigation to the orchards where the plots were located.

Soil Sampling and Computations.—Before and after each irrigation, soil samples for moisture determinations were taken on each plot (except as otherwise noted) to a depth of 6 feet. Occasionally extra samples were obtained in the middle of the period between irrigations.

All sampling was done with an improved soil tube.[8] First the soil mulch was removed, and then samples were taken from the established points in each plot at 1-foot intervals to a depth of 6 feet. Standard methods were used in weighing and drying the samples and in computing the moisture percentages. The average moisture content of each foot in depth was plotted as a graph, from which the average soil-moisture loss was obtained for each period between irrigations. The water in the soil was computed by the formula $D = \frac{Pvd}{100}$, in which D represents the equivalent depth of water in inches; P the change in moisture percentage; v the apparent specific gravity of the soil (sometimes referred to as the volume weight); and d the depth of soil in inches from which the moisture percentage P was obtained.

Losses for 30-day periods were then calculated. These losses were then plotted as a seasonal-use-of-water curve, and the average transpiration for each month was obtained directly from the curve. *Transpiration* may be defined as the moisture loss by plants. It is employed here instead of the more common *consumptive use* because most of the loss by evaporation (which the latter term covers) is from the mulch, which has been excluded in these investigations.

In all orchards where the straight-furrow method of irrigation was used, samples were taken from the irrigated soil between the tree rows and from the unirrigated soil in the tree rows of each experimental plot.

The outline between the irrigated and unirrigated soil was determined

[8] Veihmeyer, F. J. An improved soil-sampling tube. Soil Sci. 27:147–52. 1929.

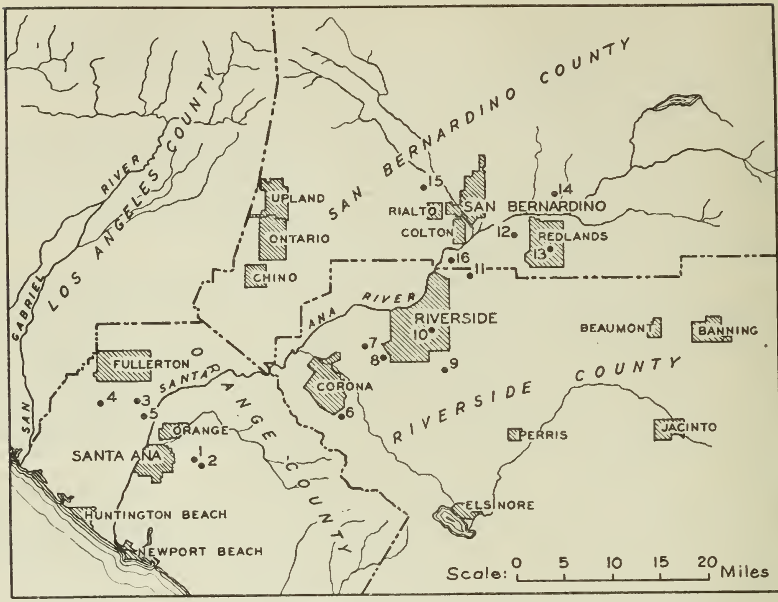

Fig. 1.—A portion of the south coastal basin of southern California, showing locations of plots.

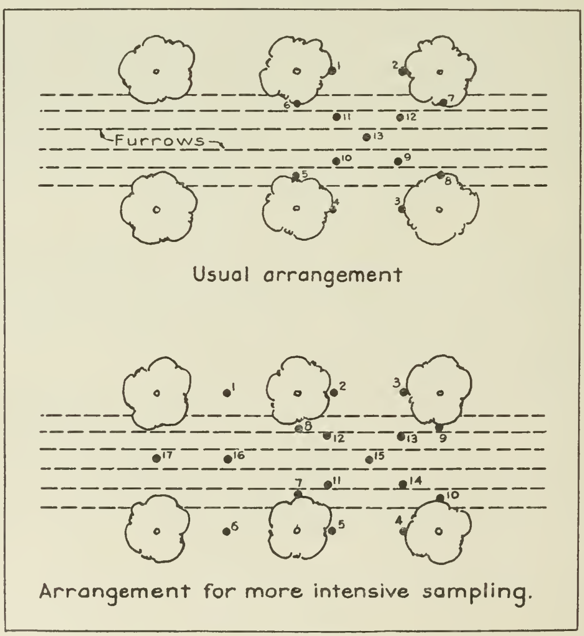

Fig. 2.—Location of sampling points in typical furrow-irrigated plots.

by driving a soil tube at angles of 30 and 60 degrees from the center of the outside furrows (nearest the trees) into the unmoistened soil (fig. 3). The percentage of the soil moistened at each irrigation was then computed.

In following the location of these wet and dry zones, in orchards where the furrows remained the same through the season, it was usually found that the percentage of soil moistened gradually increased after midsummer. At the last irrigation in the fall or early winter, practically 100 per cent of the soil was often found to be moistened, as compared with 75 to 80 per cent during midsummer.

Since samples were taken from the moistened and unmoistened soil sections of the plot, those sections had to be treated as separate units.

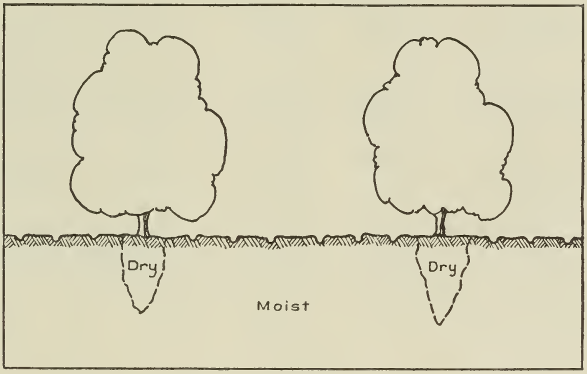

Fig. 3.—Sectional elevation of typical plot, showing moist and dry zones.

The soil-moisture-percentage averages were obtained in this investigation, not to select a time for irrigation, but solely to determine the average use of water and the average rates of moisture loss at various depths. The owner's normal irrigation practice was followed.

Citrus trees, especially those on sweet-orange root, are relatively shallow rooted; and often the roots are unevenly distributed. There is considerable variation, accordingly, in the rates at which different parts of the soil dry out. Portions will be reduced to the *permanent wilting percentage*[9] before the trees show signs of water shortage; or the trees may show definite distress before the average soil moisture at a particular depth has dropped to this wilting point. Often, as a result of such inequalities in root distribution, the rates of moisture loss are less just before irrigation than earlier in the interval.

The percentage of water applied that can be accounted for in soil-moisture increase below the mulch is here called the *irrigation efficiency*. Conversely, the soil-moisture increase represents the water applied, less losses by percolation below the root zone, runoff from the ends of the furrows, and evaporation direct to the atmosphere. Commonly, efficiency is computed from consumptive use rather than from transpiration; but that procedure was not followed in this study. Unfortunately, records of water applied for much of the work here

[9] Veihmeyer, F. J., and A. H. Hendrickson. Essentials of irrigation and cultivation of orchards. California Agr. Ext. Cir. 50:6. Revised 1943.

TABLE 1

LOCATIONS AND MAIN CHARACTERISTICS OF VALENCIA-ORANGE PLOTS IN THE COASTAL ZONE OF ORANGE COUNTY, SEASONS OF 1928 AND 1929

Orchard no. and location	Year planted	Condition of trees	Method of irrigation	Soil	
				Type	Remarks
No. 1, ½ mile N.E. of Tustin	1901	Excellent; high producers	Cross furrow	Yolo loam	Uniform light subsoil
No. 2, ¾ mile N.E. of Tustin	Unknown; old trees	Excellent; large trees	Zigzag furrow	Yolo loam	Uniform
No. 3, 1 mile E. of Anaheim	1915	Good	Straight furrow	Hanford sandy loam	Uniform to 6 feet
No. 3*a*, 1 mile E. of Anaheim	About 1895	Good	Straight furrow	Hanford sandy loam	Uniform to 6 feet
No. 4, 3 miles W. of Anaheim	1916	Fair	Cross furrow	Hanford sandy loam	Silt stratas below 2 feet
No. 5, 2½ miles S.E. of Anaheim	1917	Good	Straight and cross furrow	Hanford sandy loam	Soil heavier below 4 feet

TABLE 2

IRRIGATION DATA FOR ORANGE COUNTY PLOTS

Orchard no. and year	Irrigations April 1 to November 1		
	Irrigations	Interval	Total depth water applied
	number	*days*	*inches*
No. 1:			
1928	4	33 to 52	14.8
1929	5	29 to 47	13.8
No. 2:			
1928	3	44 to 61	20.3
1929	4	47 to 56	25.7
Nos. 3 and 3*a*:			
1928	7	23 to 37	14.4
No. 4:			
1928	4	36 to 51	9.5
No. 5:			
1929	8	8 to 32	—*

* Dash indicates data not available.

TABLE 3

Summary of Data on Transpiration of Water during Normal Irrigation Season, and Moisture Loss by Depth; Coastal Zone, Orange County, 1928 and 1929

Maturity of trees, year, and orchard no.	Depth of water transpired								Percentage of total moisture loss at various depths					
	April	May	June	July	Aug.	Sept.	Oct.	Total	First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot
	inches	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Older, vigorous trees:														
1928:														
No. 1*	1.6	2.0	2.8	3.6	3.0	2.3	1.5	16.8	35	31	13	10	7	4
No. 2	1.4	1.6	2.5	2.9	3.1	2.5	1.7	15.7	29†	35	17	14	3	2
No. 3*a*	1.3	2.3	3.5	3.5	2.9	2.3	1.8	17.6	42	28	17	11	2	0
1929:														
No. 1*	1.3	1.9	2.7	3.1	3.0	2.6	1.8	16.4	39	26	15	11	6	3
No. 2	1.0	1.5	2.0	2.3	2.5	2.3	1.8	13.4	37	31	13	11	3	5
Average of 5 records	1.3	1.9	2.7	3.1	2.9	2.4	1.7	16.0	37	30	15	11	4	3
Younger trees:														
1928:														
No. 3	1.8	1.9	2.2	2.4	2.3	2.2	1.8	14.6	55	24	12	7	1	1
No. 4*	1.1	1.3	1.6	1.6	1.4	1.2	1.0	9.2	50	30	8	6	4	2
1929:														
No. 5*	1.0	1.2	1.4	1.6	2.1	1.6	1.0	9.9	39	27	15	12	5	2
Average of 3 records	1.3	1.5	1.7	1.9	1.9	1.7	1.3	11.3	48	27	12	8	3	2
Percentage use by months, average 1928 and 1929														
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*						
Older, vigorous trees	*8*	*12*	*17*	*19*	*18*	*15*	*11*	*100*						
Younger trees	*11*	*13*	*15*	*17*	*17*	*15*	*12*	*100*						

* Average of two plots.

† Deep furrows, cultivation for which cut a high percentage of first-foot roots, account for low use in first foot.

reported were not complete enough to indicate the irrigation efficiency. In many of the areas, an excessively porous subsoil had resulted in considerable deep percolation. The efficiencies computed are, consequently, below average. In general, with careful furrow irrigation where runoff is kept at a minimum,

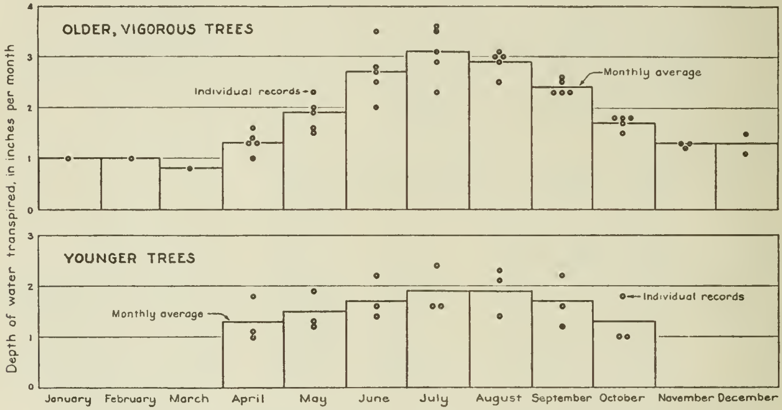

Fig. 4.—Distribution of individual monthly, and average monthly, transpiration records, Orange County, 1928–1929.

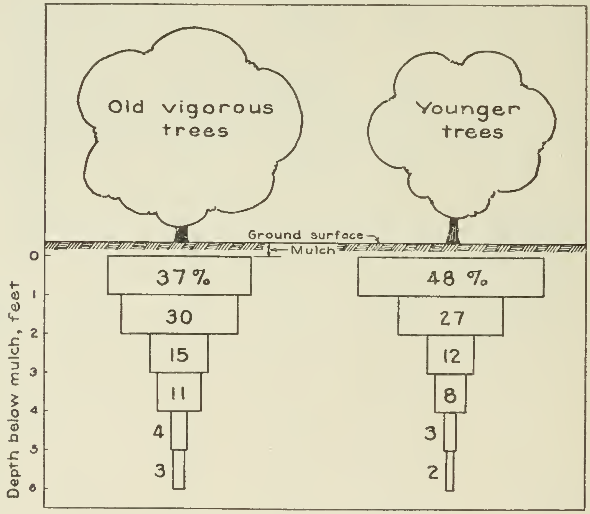

Fig. 5.—Loss of moisture by depth, Orange County, 1928–1929.

efficiencies of 70 per cent are common, and 60 per cent should be realized. In basin irrigation where there is no runoff, efficiencies may run 80 per cent or higher.

SUMMARY OF RESULTS

Coastal Zone of Orange County.—Field work to determine the transpiration of water by oranges in Orange County was conducted during 1928 and 1929. Table 1 shows locations and main characteristics of the Orange County

plots. The orchard numbers refer to the places shown in figure 1. Data on the actual irrigation applications will be found in table 2.

Table 3 summarizes results of the Orange County work, which are also shown graphically in figures 4 and 5. Differentiation is not made between trees on sweet stock and those on sour, although there would probably be a difference between the rooting habits of trees on the different roots. The transpiration of water is tabulated for each orchard for every month of the normal irrigation season. Maximum use normally occurs in July. An average seasonal requirement of 16 inches was found for the orchards with large old trees, and 11 inches for the younger orchards. Differences in the water use in the two classifications may reflect the vigor of the plantings rather than the age. These classifications were set up in the field at the time the work was started.

TABLE 4

Records of Transpiration of Water by Citrus Trees in Orange County, January to March and November to December, 1928 and 1929

Orchard no. and year	Depth of water transpired					
	Jan.	Feb.	March	Nov.	Dec.	Total for 12 months
	inches	*inches*	*inches*	*inches*	*inches*	*inches*
No. 1:*						
1928	...	...	...	1.2	1.5	....
1929	1.0	1.0	0.8	1.3	1.1	21 6
No. 2:						
1929	...	...	...	1.3	...	....

* Plots covered with canvas during storms to prevent rain from reaching soil.

In the Orange County investigations some data were obtained regarding transpiration in months other than those of the normal irrigation season (table 4). By covering orchard no. 1 plots with canvas during storms, it was possible to carry on the soil-moisture studies during the winter.

Interior Zone of Riverside and San Bernardino Counties.—Observations and measurements to determine the transpiration of water by citrus in the interior zones of Riverside and San Bernardino counties were started in 1930 and carried through 1935 in the Corona, Arlington, Riverside, Highgrove, Redlands, Highland, and Rialto areas. One or more representative orchards were chosen in each area.

In selecting locations the same factors were considered as in Orange County. Figure 1 shows locations of the different plots; table 5 the main characteristics of each orchard.[10]

Table 6 summarizes findings for the interior zone, while table 7 gives the average depth of water transpired. The average percentage distribution of moisture loss is shown on page 19. The data are shown graphically in figures 6 and 7. Conceivably, some of the soil-moisture loss in the no. 7 plots may have

[10] The studies made in the Corona area from 1933 to 1935 were in coöperation with the Temescal Water Company. Field work was performed by D. A. Newcomb of the Corona Foothill Lemon Company at the expense of the former company.

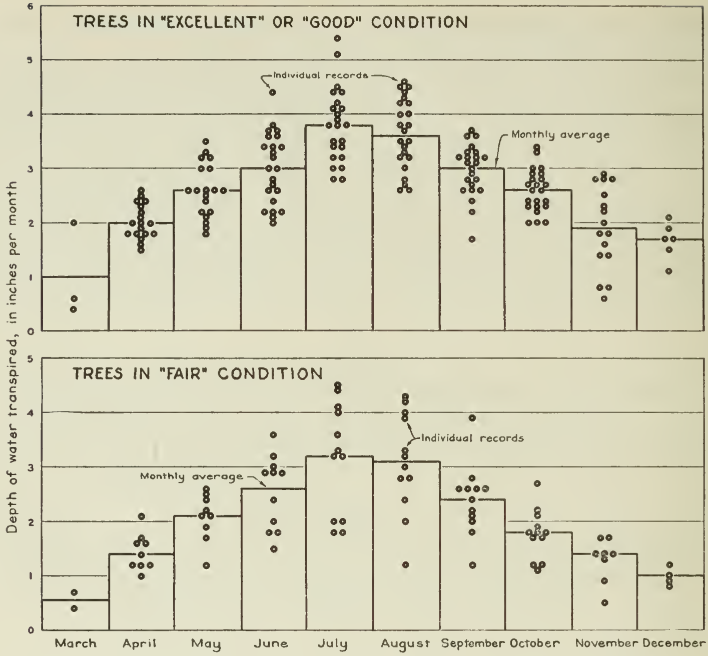

Fig. 6.—Distribution of individual monthly, and average monthly, transpiration records, interior zone, Riverside and San Bernardino counties, 1930–1935.

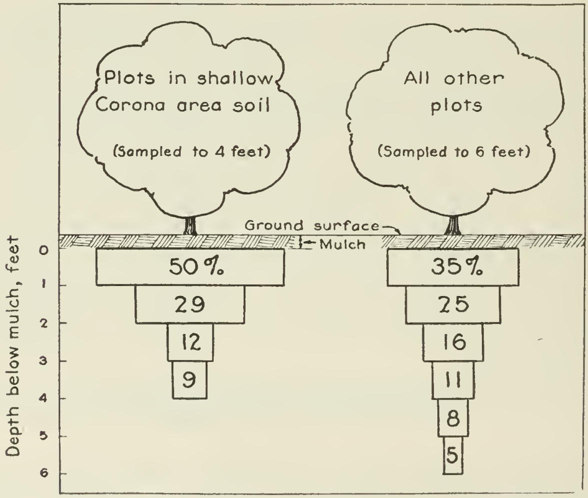

Fig. 7.—Loss of moisture by depth, interior zone, Riverside and San Bernardino counties, 1930–1935.

TABLE 5

LOCATIONS AND MAIN CHARACTERISTICS OF PLOTS IN INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, SEASONS OF 1930 TO 1935

Orchard no., location, and crop	Year planted*	Condition of trees	Method of irrigation†	Soil	
				Type	Remarks
No. 6*a*, 1½ miles S.W. of Corona, navel oranges	1900	Excellent	Straight furrow	Yolo loam	Increasing gravel with depth
No. 6*b*, 2.7 miles S. of Corona, navel oranges	Mature	Excellent	5 furrows, wet 80 per cent		
No. 6*c*, 3.5 miles S.W. of Corona, Eureka lemons	Mature	Good	6 furrows, wet 90 per cent		
No. 6*d*, 2.5 miles S.W. of Corona, Lisbon lemons	Mature	Excellent	5 furrows, wet 70 per cent		
No. 6*e*, 1.2 miles S. of Corona, navel oranges	Mature	Very good	4 furrows, wet 70 per cent	Yolo gravelly loam	Gravel below 4 feet
No. 6*f*, 2.4 miles S.E. of Corona, navel oranges	Mature	Fair	5 furrows, wet 60 per cent		
No. 6*g*, 3.3 miles S.E. of Corona, Eureka lemons	Mature	Fair	5 furrows, wet 65 per cent		
No. 6*h*, south of Corona, navel oranges	Mature	Fair	6 furrows, wet 75 per cent		
No. 6*i*, 3.0 miles S.E. of Corona, navel oranges	Mature	Excellent	5 furrows, wet 75 per cent		
No. 7, 2 miles S.W. of Arlington, navel oranges	Mature	Fair	Straight furrow	Hanford sandy loam	Heavier subsoil
No. 8*a*, 1½ miles S.E. of Arlington, navel oranges	1910	Excellent	Straight furrow	Placentia loam	......
No. 8*b*, 1½ miles S.E. of Arlington, Valencia oranges	1910	Excellent	Straight furrow	Hanford sandy loam	......
No. 9*a*, 2 miles E. of Riverside, navel oranges	1916	Fair			
No. 9*b*, 2 miles E. of Riverside, grapefruit	1916	Fair	Straight furrow	Ramona loam	Subsoil uniformly heavy
No. 9*c*, 2 miles E. of Riverside, Valencia oranges	1916	Fair			
No. 9*d*, 2 miles E. of Riverside, navel oranges	1916	Fair			
No. 10, 1 mile E. of Riverside, navel oranges	Before 1900	Excellent	Straight furrow	Greenfield sandy loam	Soil uniform
No. 11, at Highgrove, navel oranges	About 1910	Excellent	Straight furrow	Ramona loam	Fine texture on top
No. 12, 3 miles S.W. of Redlands, Valencia oranges	1913	Excellent	Straight furrow	Hanford sandy loam	Very uniform
No. 13*a*, 1 mile S.E. of Redlands, navel oranges	Mature	Good	Straight furrow	Placentia loam	Dense clay loam below 2½ feet
No. 13*b*, 1 mile S.E. of Redlands, navel oranges	Mature	Good	Straight furrow	Hanford sandy loam	......
No. 14, 1 mile N.E. of Highland, navel oranges	Before 1900	Excellent	Straight furrow	Ramona loam	Some clay below 3 feet
No. 15, 3 miles N. W. of Rialto, grapefruit	Mature	Excellent	Straight furrow	Hanford sandy loam	Increasing coarseness with depth
No. 16, near Colton, navel oranges	Mature	Fair	Sprinkler	Placentia loam	Subsoil heavy below 2 feet

* When planting date is not known, relative age is given.
† Percentages wet refer to surface area.

TABLE 6

TRANSPIRATION BY MONTHS, MOISTURE LOSS BY DEPTH, AND IRRIGATION DATA FOR INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, 1930 TO 1935

Orchard no. and year	Depth of water transpired											Percentage of total moisture loss at various depths						Irrigation data, Apr. 1 to Nov. 1			
	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Apr. 1 to Nov. 1	First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Irrigations	Interval	Total water applied	Efficiency
	inches	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*number*	*days*	*inches*	*per cent*
No. 6*a*:																					
1930*....	...	1.5	2.1	3.0	3.8	4.3	3.4	3.0	2.3	...	21.1	32	30	17	12	6	3	6	28	33.0	..
1931*....	...	2.0	2.2	3.4	4.4	3.2	2.6	2.4	...	...	20.2	..	..	..	..	..	..	7	28	31.0	..
No. 6*b*:																					
1933†....	...	...	...	3.2	3.4	4.0	2.7	2.6	2.0	...	....	..	..	..	..	..	..	5	12–34	73.0	21
1934†....	...	2.4	3.2	2.2	3.8	4.2	3.7	2.4	0.6	...	21.9	47	30	12	11	..	..	8	17–34	57.8	34
1935†....	0.6	2.1	2.5	2.6	3.8	3.8	2.6	3.0	2.8	1.7	20.4	41	28	16	15	..	..	10	25–34	64.8	34
No. 6*c*:																					
1933†....	...	...	...	2.4	3.9	4.2	2.8	2.0	2.8	...	....	..	..	..	..	..	..	10	12–25	33.3	54
No. 6*d*:																					
1933†....	...	...	...	2.6	3.0	3.0	2.6	2.0	1.4	...	....	..	..	..	..	..	..	6	28–35	32.5	37
1934†....	...	1.8	3.2	3.4	3.0	2.6	3.6	3.4	0.8	...	21.0	57	30	6	7	..	..	7	28–32	41.4	46
1935†....	0.4	1.7	2.0	2.2	2.8	3.5	3.3	2.3	1.8	1.5	17.8	50	30	11	9	..	..	9	22–33	47.9	42
No. 6*e*:																					
1933†....	...	...	...	2.8	2.8	2.8	3.2	2.6	1.8	...	....	..	..	..	..	..	..	6	28	25.4	62
1934†....	...	2.0	3.3	2.1	3.5	3.4	2.2	2.3	1.4	...	18.8	51	29	13	7	..	..	9	28	37.2	74
1935†....	2.0	2.0	2.6	2.7	3.2	3.8	3.2	2.8	1.6	1.1	20.3	46	30	14	10	..	..	10	24	37.8	44
No. 6*f*:																					
1933†....	...	...	...	2.0	2.0	2.4	2.6	2.1	1.7	...	....	..	..	..	..	..	..	5	28	19.0	54
1934†....	...	1.6	1.7	2.4	2.0	2.8	2.6	2.2	0.5	...	15.3	56	27	11	6	..	..	8	28	33.0	41
1935†....	0.4	1.2	2.4	2.8	3.2	2.8	2.6	1.8	1.4	1.2	16.8	53	27	13	7	..	..	10	24	34.7	42
No. 6*g*:																					
1933†....	...	...	...	1.5	1.8	2.0	2.2	1.9	1.4	...	....	..	..	..	..	..	..	6	28	39.3	26
No. 6*h*:																					
1933†....	...	...	...	1.8	1.8	1.2	1.2	1.2	0.9	...	....	..	..	..	..	..	..	6	26–30	20.4	39
No. 6*i*:																					
1934†....	...	2.4	2.6	2.0	3.5	3.2	2.9	2.2	0.8	...	18.8	52	29	11	8	..	..	8	28	33.1	51

No. 7:																					
1931*¶	...	2.0	3.1	4.0	4.0	3.2	3.1	3.0	...	...	22.4	..	..	..	..	..	..	6	30	29.7	..
1932*¶	...	3.6	4.3	5.3	6.4	6.2	4.3	2.6	...	...	32.7	31	19	16	13	11	10	9	10–45	34.2	..
Nos. 8a, 8b:																					
1930*	...	2.6	3.0	3.6	4.4	4.4	3.1	2.7	...	...	23.8	30	24	17	14	8	7	6	30	25.9	..
No. 9a:																					
1930	...	1.6	2.1	3.2	4.5	3.9	2.1	1.1	1.7	0.9	18.5	33	26	18	10	7	6	5	30–38	21.6	..
No. 9b:																					
1930	...	1.2	2.5	2.9	3.3	3.0	2.0	1.2	2.5	0.8	16.1	37	25	13	9	10	6	5	30–38	21.6	..
No. 9c:																					
1930	...	1.2	1.2	1.8	4.0	3.3	1.8	1.7	1.3	1.0	15.0	42	24	13	11	6	4	5	30–38	21.6	..
No. 9d:																					
1931	...	2.1	1.9	3.6	4.1	3.2	2.6	1.8	...	...	19.3	46	27	15	5	4	3	8	21–30	31.3	..
1932	...	1.7	2.1	3.0	4.4	4.3	2.4	1.7	1.4	...	21.0	34	26	14	9	9	8	..	..	..	..
1933	0.7	1.0	2.2	2.9	3.6	4.2	2.8	1.8	...	...	18.5	37	27	15	9	8	4	7	20–50	37.3	53
No. 10:																					
1930*‖	...	2.2	1.8	2.2	3.2	2.7	2.4	2.3	2.2	...	16.8	41	24	14	8	7	6	12	15	26.8	..
1931*	...	...	3.0	3.3	4.0	2.6	1.7	2.0	...	...	....	43	23	13	8	7	6	7	30	30.2	..
No. 11:																					
1930*	...	1.9	2.6	3.6	4.2	3.5	2.8	2.7	2.5	2.1	21.3	38	26	14	8	8	5	6	30	25.9	..
1931*	...	1.6	1.9	3.7	5.4	4.5	3.1	3.3	...	...	23.5	..	..	..	..	..	..	6	30	27.1	..
No. 12:																					
1930*	...	1.8	2.2	3.7	4.1	4.0	3.3	2.9	2.8	1.7	22.0	32	25	19	14	6	4	6	25	....	..
No. 13a:																					
1930‡	...	1.6	3.3	7.0	8.0	5.0	3.7	2.7	...	...	31.3	34	24	18	12	5	4	8	15–30	34.5	..
No. 13b:																					
1930§	...	2.0	2.5	5.4	6.0	4.4	4.3	2.2	...	...	26.8										
No. 14:																					
1930*	...	1.8	2.4	3.4	4.5	4.5	3.2	2.9	2.9	1.9	22.7	35	21	16	11	9	8	6	30	28.0	..
1931*	...	1.8	2.6	3.8	4.1	3.7	3.0	2.4	...	...	21.4	31	22	16	13	11	7	7	30	34.3	..
No. 15:																					
1930*‖	...	2.3	2.6	3.0	3.4	3.3	3.2	2.7	...	...	20.5	32	25	17	13	8	5	9	18	21.6	..
1931*‖	...	2.5	3.5	4.4	5.1	4.6	3.6	2.8	...	...	26.5	35	25	15	10	9	6	10	18	24.5	..
No. 16:																					
1931*	...	1.4	2.6	2.9	3.2	4.0	3.9	2.7	...	...	20.7	..	..	..	..	..	..	17	10–15	30.6	..

* Average of two plots in orchard.
† Porous subsoil; sampling only to 4-foot depth.
‡ Heavy covercrop until August 12. Not included in averages.
§ Covercrop within boundaries of plot hoed down periodically. Covercrop outside may have influenced transpiration. Not included in averages.
¶ Not included in averages. Some question as to validity of data.
‖ Alternate middles watered at each irrigation.

represented downward movement of moisture. Those plots are therefore not included in the averages.

The individual monthly records of transpiration varied considerably. Some variation is inherent in any soil-moisture sampling work because of unevenness in root distribution and in soil characteristics. (It is impossible to obtain repeated samples from exactly the same spot.) The small error involved is not cumulative, however, and tends to be eliminated as the number of records increases. Figure 6 shows the individual monthly variations graphically; but, as will be noted from table 6, even such great variations do not much affect the seasonal totals.

TABLE 7

AVERAGE TRANSPIRATION FOR PLOTS IN INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, 1930 TO 1935

Condition of trees	Depth of water transpired										
	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total April 1 to Nov. 1
	inches	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*	*inches*
Excellent and good...	1.0	2.0	2.6	3.0	3.8	3.6	3.0	2.6	1.9	1.7	20.6
Fair..................	0.6	1.4	2.1	2.6	3.2	3.1	2.4	1.8	1.4	1.0	16.6

Where conditions were comparable, an effort was made to determine whether the records for one year differed significantly from those of another. No such differences were found. Apparently, furthermore, there are no significant differences in transpiration in the several areas within the interior zone.

In the fall of 1936 a study was made to determine whether trunk size, tree height, or the percentage of ground covered (tree size in relation to ground area per tree) had any bearing on transpiration as determined in 1930 and 1931 for the particular plot trees in several of the plantings. No such relation was indicated.

When the field work was under way, all orchards were classified with respect to condition of trees as "excellent," "good," and "fair." Seasonal totals are remarkably consistent for all "excellent" and "good" orchards except nos. 13*a* and 13*b*, where practices were not comparable. "Fair" orchards vary in transpiration from about the average for the better orchards to about 70 per cent of the average. For them, accordingly, transpiration is averaged separately.

Results for nos. 13*a* and 13*b* are not included in the averages, because of the heavy covercrop grown there through most of the summer. Orchard 13*a* was sampled without disturbing the covercrop. Orchard 13*b* was periodically hoed in an attempt to offset the influence of the covercrop, which surrounded it and (until after the hoeing) grew upon it; but the cover may well have had some part in depleting soil moisture from this plot. Rates of moisture extraction in 13*a* as compared with averages for all plots are considered significant in indicating increased transpiration under summer covercropping.

INFORMATION REGARDING SALTS IN THE SOIL SOLUTION

The chemical composition of an irrigation water may change the character of the soil to which it is applied, and affect the crop.[11] The irrigation waters used on all plots were of good to excellent quality.[12] Total salt content, boron content, and sodium percentage were favorable.

Regardless of the nature of the irrigation water, questions may arise whether the amounts used, plus rainfall, were adequate to prevent salt accumulations near the roots. Since all irrigation waters of the south coastal basin contain more or less salt, and since the moisture extracted by roots contains very little, the accumulations are inevitable unless some salts are leached from the root zone by the combined effect of irrigation water and rainfall.

One may measure the soluble salts present in a soil approximately by making water extracts of representative soil samples and then determining the amounts of the various soluble constituents in the extract. Such was the procedure with the eight interior-zone orchard plots listed in table 8. Soil samples to a depth of 5 feet were taken before June, 1931, and to a greater depth in December, 1937, just before the fall rains. In 1937, samples were obtained late in the irrigation season and might be expected to show a maximum seasonal salt accumulation. The 1931 sampling was done shortly after the end of the winter rains. As far as can be learned, there have for years been no significant changes in source of water, cultural practices, or average seasonal irrigation applications. Average rainfall at Riverside for 1931 to 1937 was 93 per cent of that for 1924 to 1941, and apparently about equal to a long-time normal, judging from a sixty-three-year Los Angeles record.

Water extracts were made using one part of oven-dried soil to five parts of distilled water. Table 8 summarizes the analyses. The data indicate that with the amounts of water applied, plus rainfall, salt accumulation is not a problem in the particular orchards investigated.

CONCLUSIONS

Coastal Zone.—The following conclusions are warranted from the investigations of 1928 and 1929 in Orange County, but are subject to the limitations inherent in this type of study. Apparently, however, the underlying data closely represent water use under the particular conditions.

1. Transpiration of water by citrus trees, characterized as large, vigorous, and mature, in Orange County averaged 16 inches depth for the normal irrigation season of April 1 to November 1. (Transpiration is the water use by the crop, and does not include deep percolation losses, waste from the ends of the furrows, or surface evaporation.)

2. Transpiration of water by younger and perhaps less vigorous citrus trees in Orange County averaged slightly over 11 inches for the normal irrigation season.

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[11] Eaton, Frank M. Boron in soils and irrigation waters and its effect on plants, U. S. Dept. Agr. Tech. Bul. 448:29–34. 1935.

[12] Anonymous. South coastal basin investigations—detailed analyses showing quality of irrigation waters. California State Dept. Pub. Works, Div. of Water Resources Bul. 40-A:i–xi + 1–131. 1933.

TABLE 8

ANALYSES OF ONE TO FIVE WATER EXTRACTS OF 1931 AND 1937 SOIL SAMPLES FROM INTERIOR-ZONE PLOTS

Orchard no. and sample depth	Specific electrical conductance at 25°C		Total solids		Bicarbonate (HCO_3)		Sulfate (SO_4)		Chloride (Cl)	
	1931	1937	1931	1937	1931	1937	1931	1937	1931	1937
	$K\times10^5$	$K\times10^5$	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
No. 6*a*:										
0–1 foot........	20.6	28.5	250	350	65	..	71	..	0	5
1–2 feet........	26.3	21.4	250	250	40	..	54	..	20	0
2–3 feet........	11.9	16.0	150	150	47	..	32	..	0	0
3–4 feet........	21.6	13.8	200	200	44	..	27	..	14	1
4–5 feet........	12.3	25.5	100	150	44	112	51	..	4	1
5–6 feet........	....	26.7	...	200	..	..	..	..	..	3
6–7 feet........	....	28.8	...	200	..	..	..	..	..	7
No. 7:										
0–1 foot........	46.0	51.7	300	500	44	69	62	..	10	47
1–2 feet........	19.5	20.0	200	250	36	40	41	42	2	0
2–3 feet........	30.1	34.7	250	250	29	40	42	92	6	0
3–4 feet........	31 0	30.5	250	250	36	29	41	..	10	0
4–5 feet........	32.1	27.6	250	250	29	25	34	65	15	1
5–6 feet........	....	25.6	...	300	..	36	..	50	..	3
6–7 feet........	....	30.7	...	250	..	36	..	40	..	10
7–8 feet........	....	27.9	...	200	..	..	..	..	..	14
8–9 feet........	....	20.6	...	250	..	69	..	..	..	23
No. 10:										
0–1 foot........	29.5	48.2	200	525	47	58	28	131	12	24
1–2 feet........	22.2	16.8	150	200	47	44	23	20	3	1
2–3 feet........	19.1	32.6	200	150	44	10	23	11	7	0
3–4 feet........	12.6	9 0	100	50	36	29	15	11	0	1
4–5 feet........	14.1	8.7	50	100	36	25	16	..	2	0
5–6 feet........	....	13.7	...	100	..	58	..	..	..	0
6–7 feet........	....	15.2	...	150	..	69	..	..	..	0
7–8 feet........	....	16.5	...	100	..	80	..	15	..	1
8–9 feet........	....	14.6	...	150	..	62	..	..	..	0
No. 11:										
0–1 foot........	22.4	40.0	300	400	98	..	52	..	5	3
1–2 feet........	31.9	19.5	250	200	47	..	52	..	8	1
2–3 feet........	47.0	18.5	350	175	40	..	65	..	24	0
3–4 feet........	46.4	20.4	350	200	33	..	94	..	22	3
4–5 feet........	17.9	16.7	150	150	36	..	36	..	3	3
5–6 feet........	....	19.7	...	200	..	..	..	..	..	2
6–7 feet........	....	21.2	...	200	..	..	..	..	..	1
7–8 feet........	....	17.6	...	100	..	..	..	..	..	1
8–9 feet........	....	13.3	...	200	..	..	..	..	..	3
No. 12:										
0–1 foot........	22 8	14.0	200	200	40	54	62	..	2	3
1–2 feet........	16.2	11.1	150	150	25	40	16	..	0	1
2–3 feet........	26.8	9.1	200	100	36	..	27	..	9	0
3–4 feet........	27.9	.14.3	300	100	51	80	26	..	10	2
4–5 feet........	18.1	14.0	150	100	62	62	18	25	4	0
5–6 feet........	....	22.2	...	500	..	69	..	31	..	0
6–7 feet........	....	19.9	...	150	..	87	..	..	..	1
7–8 feet........	....	14.8	...	100	..	80	..	..	..	2
8–9 feet........	....	13.7	...	100	..	62	..	20	..	0
Nos. 13*a* and 13*b*:										
0–1 foot........	22.4	24.4	250	400	36	33	43	47	6	0
1–2 feet........	20.2	11.1	200	150	51	25	30	29	11	0
2–3 feet........	16.4	12 7	200	200	36	29	21	20	3	0
3–4 feet........	19.1	18.0	250	250	62	18	14	20	2	0
4–5 feet........	20.4	18.8	200	100	44	..	21	..	6	4
5–6 feet........	....	16.3	...	250	..	47	..	..	..	4
No. 14:										
0–1 foot........	....	33.0	...	450	..	..	..	62	..	3
1–2 feet........	....	17.2	...	200	..	..	..	..	..	1
2–3 feet........	12.9	11.1	100	150	40	..	..	..	0	0
3–4 feet........	9.0	9.6	50	100	33	..	..	..	0	0
4–5 feet........	10.9	9.9	50	100	44	..	..	..	0	0
5–6 feet........	....	10.2	...	100	..	..	..	..	..	0
6–7 feet........	....	9.8	...	100	..	..	..	..	..	0
7–8 feet........	....	10.1	...	100	..	..	..	..	..	1
8–9 feet........	....	8.8	...	125	..	..	..	..	..	1
No. 15:										
0–1 foot........	44.1	27.0	...	400	..	..	57	..	..	3
1–2 feet........	22.3	22.8	250	150	44	..	44	..	0	9
2–3 feet........	15.4	19.8	100	200	36	..	32	..	0	1
3–4 feet........	27.0	13.0	200	100	58	..	21	..	5	0
4–5 feet........	13.7	9.5	150	200	40	...	16	..	0	0
5–6 feet........	....	9.3	..	100	..	..	..	..	..	0

3. Relative rates of moisture loss by depth below mulch averaged:

Depth of sampling	Older trees, per cent	Younger trees, per cent
First foot	36	48
Second foot	30	27
Third foot	15	12
Fourth foot	11	8
Fifth foot	4	3
Sixth foot	3	2

No differentiation was made between trees growing on different root stocks.

4. Rates of transpiration per month gradually increased from a low in winter to a maximum of about 3 inches per month in July and August for the older orchards. The younger orchards averaged 1.9 inches per month for July and August.

Interior Zone.—The following conclusions are warranted from the investigations in the interior zone:

1. Transpiration of water by citrus trees in "excellent" and "good" condition in the interior zone averaged 21 inches for the normal irrigation season, April 1 to November 1.

2. Transpiration for citrus trees in "fair" condition averaged 17 inches, but in some such orchards the use was as high as for trees in "excellent" condition.

3. Relative rates of moisture loss by depth below mulch averaged:

Depth of sampling	Normal deep soils, per cent	Shallow Corona area soils, per cent
First foot	36	50
Second foot	25	29
Third foot	16	12
Fourth foot	11	9
Fifth foot	7	...
Sixth foot	5	...

The soils of the Corona area were exceedingly porous below 4 feet.

4. Average rates of transpiration per month gradually increased from a low in winter to a maximum of about 3.7 inches for July and August.

5. Results from orchard no. 13*a* with a summer covercrop showed transpiration 50 per cent greater for the season than the average for all summer clean-cultivated orchards. In individual months these results indicate an increase of over 100 per cent when the covercrop is most vigorous.

6. Although efficiencies of 70 per cent are obtainable with furrow irrigation, many orchards operate at much lower ones. Though the causes of low efficiency in the plots herein reported upon were not ascertained, possible causes are (1) variations in percolation along the furrows, (2) deep percolation below the root zone, and (3) runoff from the lower ends of the furrows.

7. Judging from salt-balance studies conducted six years apart, the irrigation practices plus rainfall under the conditions of these investigations had been adequate to prevent salt accumulations in the soil within the rooting zone.

15*m*-4,'44(9299)